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VuRA: A proposal for calculating vulnerability and risk in rock art sites. The experience in Foz Côa

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ABSTRACT

As part of a project with very ambitious goals (*LandCRAFT - the sociocultural contexts of art from Recent Prehistory in the Côa Valley*), the authors were entrusted with tasks related to the conservation of a large set of rock art sites. In order to achieve these goals, and given their complexity, a standardized inspection and measurement strategy was designed to determine the degree of vulnerability and risk of this group of archaeological sites.

In a research area in which proposals and bibliographic references are particularly rare, the developed formula has reached such a high level of complexity and interest that its publication and submission to the analysis and criticism of the scientific community has been deemed necessary. Indeed, we consider that scientific dissemination could not only improve this formula but also turn it into a useful tool for public use.

Consequently, we would like to present here the first version of VuRA (Vulnerability of Rock Art), an integrated set of record sheets aimed at determining vulnerability and risk in rock art sites. This proposal combines detailed field observation with territorial information and the support of data offered by other disciplines (archaeology, chemistry, geotechnics, etc.), with a level of detail and complexity that can be regulated by the editors, depending on the objectives of the study. In the case of the LandCRAFT project, VuRA was used to define in detail the management strategies (protection, presentation, conservation, etc.) of the set of sites covered by the project.

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1. Introduction

It is not the purpose of this paper to discuss the seriousness of the deterioration affecting rock art sites; therefore, we will leave this task to experts on the issue [1] and simply assume the reality of the difficult situation rock art is facing. Nevertheless, given our experience and responsibilities in this field, we consider ourselves capable of contributing new ideas to help tackle this problem, so we will make some suggestions in the following pages. Perhaps as a second premise, in which we also agree with the aforementioned authors [1], we affirm that it is necessary to renew, or even reinvent, the models of rock art heritage management, at least in the geographies we know. Along the same lines, we have also participated in the elaboration of an innovative reflection document [2] whose reading may complement some of the ideas expressed in this paper.

When dealing with cultural heritage management, three interrelated fields of action are usually distinguished [3]: 1) its knowledge, quantification and valuation; 2) its protection, through a wide range of strategies; and 3) its dissemination and public use, to foster its social appreciation as well as the benefit of local communities. This article discusses points 1 and 2 and argues that for the design of effective protection policies it is essential to have an updated catalogue of archaeological sites, with very detailed information on their state of conservation and future risks. Otherwise, as we have often seen, any potential actions implemented will not respond to real needs and will therefore be ineffective. Unfortunately, however, there are few examples of cultural heritage management strategies which take into account the site's state of conservation and the level of risk to which it is exposed.

In the literature related to risk [4], two complementary concepts are defined: vulnerability (characteristics and state of the object) and hazard (factors that can cause deterioration). Both are necessary for the quantification of risk and for the design of protection strategies: vulnerability allows the correction of the object's weaknesses; knowledge of hazardousness facilitates the control of

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degradation factors. To define the joint study of vulnerability, hazard and risk at rock art sites we use the term 'Vulnerability Report' [5].

However, it should be noted that there is a certain imbalance in the level of research on these two items, with a reasonable number of studies applied to vulnerability and far fewer aimed at studying hazard.

Indeed, as already stated, it is possible to consult a considerable number of proposals for the characterisation and diagnosis (vulnerability) of groups of sites with rock art. We could even divide them into different categories: on the one hand, mere diagnostic systems (determination of types of degradation and their degree of severity) [6,7]; on the other hand, more ambitious proposals aimed at cataloguing and recording [8] and even others which suggest specific conservation and protection actions [9,10]. However, all of them share a weakness: they are designed on the basis of the recording of visible pathologies, proposing, in the best of cases, actions to correct them. Consequently, this methodology is insufficient when it comes to preventing alteration: it is also necessary to consider risk assessment and, therefore, hazard studies.

The proposal presented in this paper (VuRA) was designed and tested in parallel to a rock art research project [11] in which we participated as part of the conservation team. The LandCRAFT project aimed at improving the study and characterisation of a - little known - group of shelters with post-Palaeolithic rock art (Fig. 1), located in the same area as the magnificent Palaeolithic

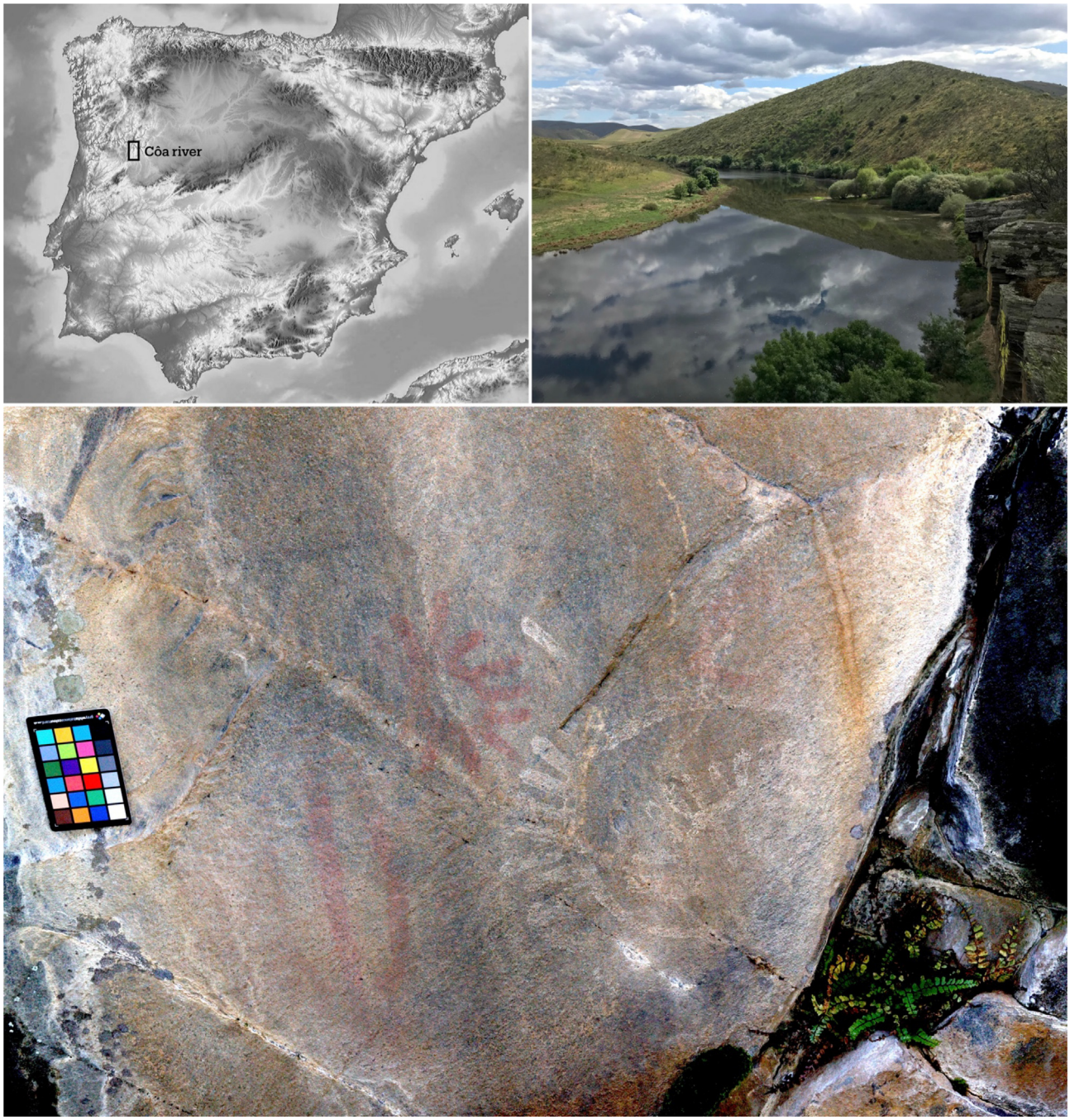

Fig. 1. Above left, map of the Iberian Peninsula showing the location of the study area; on the right, landscape (Côa river) from Ribeira de Piscos site; below, prehistoric paintings of Poço Torto site.

art group of Foz Côa (UNESCO World Heritage). The study currently covers a set of 11 shelters, and our team was entrusted with the *"production of site management plans based on-site diagnosis"*, for which we developed the VuRA tool.

2. Research aim

The aim was to design and test a comprehensive system for recording and processing information which would allow us to find out not only the current state of conservation but also the possible future evolution of a set of sites with rock art. This system should accumulate observations on the sensitivity of the object, the state of conservation and the potential impact of different agents of degradation in order to quantify the potential level of degrading impact on the site.

Taking this as a departing point, the tool should facilitate the design of measures to correct and control deterioration (management). To meet this objective, and taking into account other similar experiences, a system of record sheets was designed and applied to all the sites. This has enabled us to test the validity of the method, while awaiting its evolution and improvement.

3. Materials and methods

3.1. Risk

As indicated above, the level of risk is obtained (either by addition or multiplication) from the values of vulnerability and hazardousness, so the quantification of both is the most essential previous task. The existence of interesting experiences in the study of the vulnerability of rock art was also acknowledged, but more scarcely in the case of hazardousness, which explains the lesser development of risk studies in archaeological heritage.

In turn, hazardousness can be approached at two levels: territorial and local. The first refers to the study of factors that affect a more or less wide geographical area and that equally influence a diverse set of heritage sites. These data (e.g. climate, seismicity, etc.) are often obtained from public and even geo-referenced information sources and can be incorporated into GIS applications. In parallel, the study of hazard at the local level tries to offer an accurate quantification of these factors on a smaller scale, almost always unique to individual sites (e.g. microclimate). A study of this type requires very detailed quantification (inspection and measurement) processes that are not always feasible in financial and temporal terms.

Moreover, and obviously, in order to quantify hazard it is essential to establish a list of the deterioration factors that can interact with the cultural property. In the field of preventive conservation (movable heritage), a list of ten factors has been consolidated [12,13]. Despite its interest, and at least when applied to immovable heritage, this list seems incomplete and gives excessive prominence to some scarcely relevant agents, while other proposals [14] seem more interesting for the study of archaeological heritage. As a result of the combination of both proposals, we have decided to use a list of nine factors: biological, hydric, climatic, geo-structural, contamination, fire, light and anthropic (direct and indirect).

Perhaps the best and most ambitious example of territorial hazard quantification is the Risk Charter developed in Italy by the *Istituto Superiore per la Conservazione ed il Restauro* [15]. It is an early and innovative risk assessment project, covering the whole country and all immovable cultural heritage. Although it can incorporate individual vulnerability [16] and thus risk reports for specific sites, it is undoubtedly a very good example of the application of GIS formulas for the knowledge of territorial hazardousness.

With regard to risk calculation models [17], some predictive ones have been extensively explored in the field of Conservation [18,19]. Departing from a differentiated analysis of ten hazard factors, three different items are assessed: (A) the frequency of that factor, (B) the degree of potential impact on each object, and (C) the proportion of impact on the set of objects in a collection. The magnitude of the risk is simply the sum of A, B and C. The difficulties this method faces are diverse: it requires a good knowledge of hazardousness (alteration factors involved and their future evolution), but also an accurate estimation of the impact on the diversity of materials that constitute the cultural heritage site (vulnerability). All these reasons might explain why these methodologies have been mostly applied to the field of museum collections and not so much to the analysis of monuments and immovable sites, although there are some interesting examples of the implementation of the model to this area [20].

The examples are less common when it comes to immovable heritage, even though there are some of them which are sometimes limited to one site [21] and some others that have more generalising pretensions [22]. In both cases, the approaches to vulnerability and hazard are extraordinarily ambitious and accurate.

Another interesting example, in this case because of its simplicity, is the Art-Risk [23,24] application, also designed for architectural heritage. It is basically a form to be filled in by the user with relevant information on vulnerability as well as on local and territorial hazardousness. As for territorial hazard, this means georeferenced information (geotechnics, rainfall, thermal stress, etc.) that is incorporated into the risk calculation after entering the geographical coordinates of the building. The output variables provide results which can be used as a guide in terms of conservation and maintenance actions.

In the field of rock art, special attention should be given to a very interesting study on the Palaeolithic site of Foz Côa [25], where risk estimation is established taking into account both vulnerability observations and some local hazard factors. On this basis, an "intervention urgency scale" is proposed for the sites studied. Despite its simplicity, we believe that it is very close to the premises of our proposal: *"the intervention urgency scale is proposed as a method to prioritize future conservation work to be done in the sizeable Côa Valley open-air rock-art complex"*.

Based on the study of a significant amount of the experiences described so far, the creation of VuRA was aimed at designing a recording system that, on a single platform, would make it possible to consult information about both state of conservation and future risk, what we have called "Vulnerability Report". This, in turn, would enable us to outline any management actions needed to ensure the adequate protection of the sites studied (Fig. 2).

As the fieldwork process progressed, some amendments were made to both the sheets used and the data contained therein in order to improve their original design by adding some information that we considered relevant to the achievement of our objectives. It should also be noted that, in accordance with the strategic lines of the LandCRAFT project, all the information was organised on three levels of observation, of decreasing extension: 1) territorial setting; 2) the site (the whole set of shelters, and panels) and 3) the individual panel with prehistoric art.

Nine sheets were designed: six to be completed during the field study phase, and three additional ones, with semi-automatic calculation (Table 1):

- Sheet 1, General; a description of the geographical and legal context of the sites, as well as references to previous actions and the management and maintenance system.
- Sheet 2, Territorial setting; a detailed record of the information relating to the site's surroundings: geomorphology and relief, hydrology, land use, type of access and the visitor system,

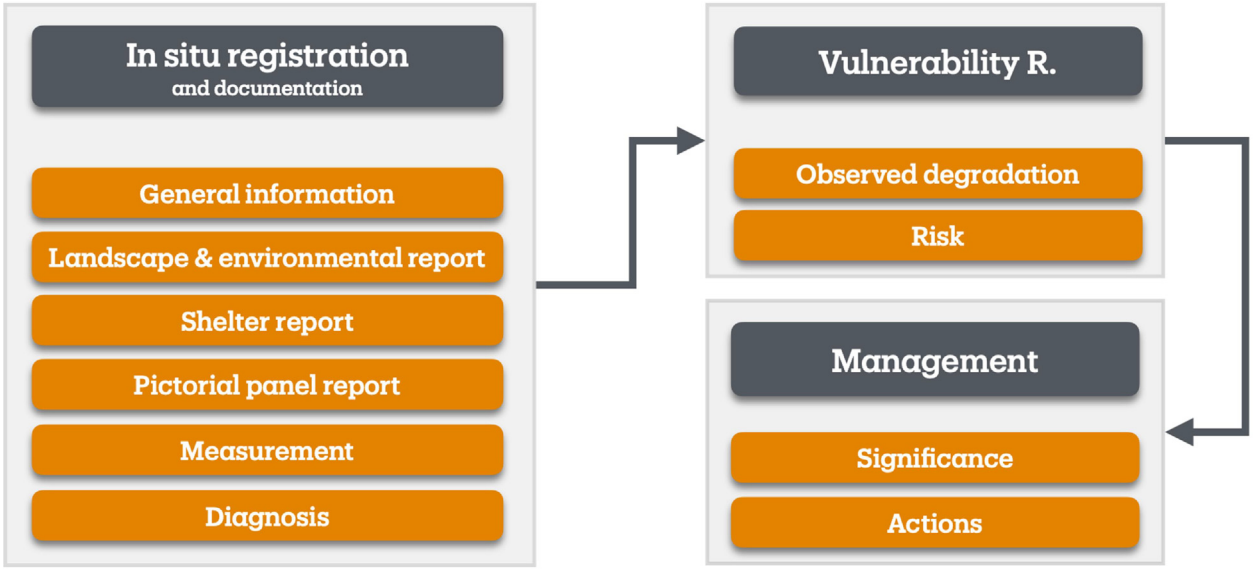

Fig. 2. Set (and phases) of VuRA system record sheets.

Table 1
Forms and main information registered in the VuRA system.

1. General	2. Landscape	3. Rock shelter	4. Pictorial panel	5. Measurement	6. Diagnosis	7. Risk	8. Value	9. Actions
Geographical data	Physiograp.	Description	Measures	Water	Aspect, evidence	Alteration and risk observed	Economic	Conserv. actions
Access	Hidrology	Lithology	Descript.	Climate	Degradation factor	Sensitivity	Aesthetic	Maintenance
Ownership & legal	Land use	Drainage	Access	Radiation	Degradation process	Hazard, threat	Symbolic	Monitorization
Historical alterations	Sources of pollution	Geologic value	Exposit.	Biology	Active?	Exposure	Scientific	
Past actions	Other threats		Techniq. (pictorial)	Pollutants	Obser. Risks: Affects visitors?			
Current managem.	Signalling		Art quality	Geo-structural	Obser. Risks: Climate change?			
	Visits/tourism		Sampling	Fire	Obser. Risks: Sudden event?			
	Fire			Anthropic (indirect)	Initial conservation actions		**Sensitivity**	
	Climatology			Anthropic (indirect)	Maintenance		**Hazard**	
	Sismicity				Monitorization		**Diagnosis**	
	Landscape value						**Significance**	
	Heritage context						**Management**	

as well as the presence of pollution sources and other types of threats that may occur in the environment. It also includes some territorial information: climate, seismicity, etc.

- Sheet 3, Outcrop/shelter; a record of the characteristics of the rocky outcrop/shelter under study and, in detail, the characteristics of the lithological support.
- Sheet 4, Panel; a detailed record of the technical characteristics of the prehistoric art, and very specifically the levels of exposure (sunlight and water drainage) determined by the orientation and slope of the surfaces; or the type of protection offered by their geomorphological setting. The relevance, visibility and state of the prehistoric painting are also assessed. In our case, much of this information was complemented by the analyses carried out by another LandCRAFT project team [26].
- Sheet 5, Local measurement of agents: this sheet describes the various processes of (local) measurement of alteration factors at each of the sites. In the LandCRAFT project, complementary measurements of local disturbance factors [26] (microclimate, pollutants, structural stability, water composition, insolation, etc.) were carried out. The VuRA approach allows for the incorporation of this local information, but can work without it, relying exclusively on territorial information. In this case, local measurements were not carried out on all sites, so they have not been used for the risk calculation (Fig. 3).

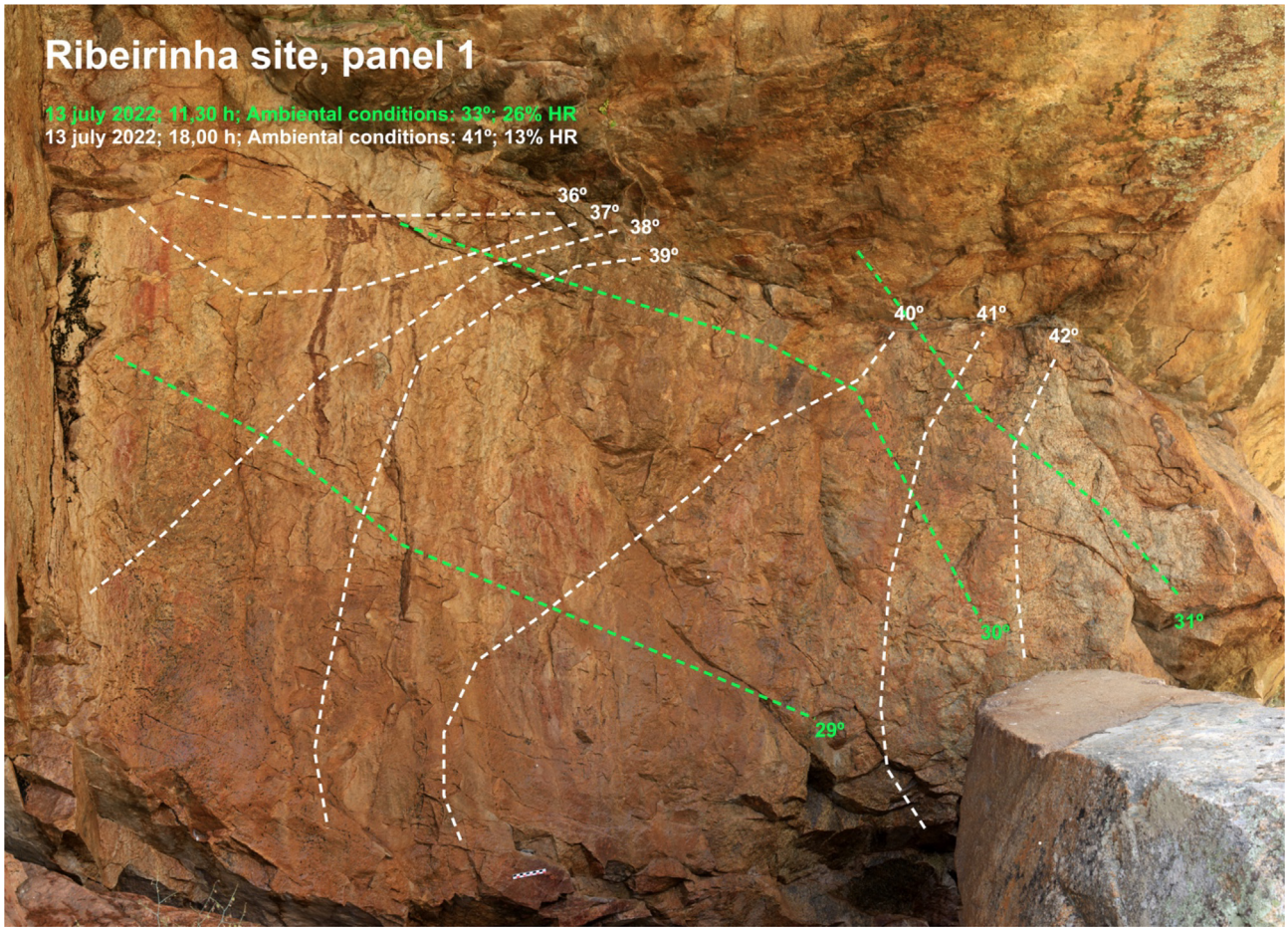

Fig. 3. Rock surface temperature at two times (11.30 and 18.00) on a hot day (July, 2022) at the Ribeirinha site.

- Sheet 6, Diagnosis: a detailed record is made of pathologies at all levels (environment, shelter, panel), determining the agent and the cause, the level of incidence (extent and intensity) and the probability of reproduction of the processes. Finally, it includes the measures proposed for the correction of these alterations, in three areas: initial corrective measures, maintenance and monitoring actions.
- Sheet 7, Risk; it automatically performs calculations for risk estimation at each site.
- Sheet 8, Heritage Value; it is used to estimate the heritage value of the site, using both information recorded in the previous sheets and data obtained from questionnaires completed by the researchers participating in the project.
- Sheet 9, Actions; it automatically produces an orderly proposal of conservation and protection actions for each site.

All this information has been organised into a Microsoft Excel file (one for each site studied), in which each of the proposed sheets (1 to 9) corresponds to a separate sheet in the Excel file. Sheets 1 to 6 have been completed in the field, through inspections and measurements carried out directly at the archaeological sites. Sheets 7, 8 and 9, meanwhile, are based on the previous sheets and provide automatic calculations based on the information recorded.

We will not offer here a detailed description of the information recorded in each record sheet, nor on the - very exhaustive - diagnostic form, since this paper is specifically aimed at describing the risk estimation method. Even though it is not an essential element of this calculation, it is necessary to point out that the so-called "observed risks" are initially analysed. This refers to the assessment made during the diagnostic process (sheet 6, Diagnosis), and responds specifically to the possibility of reproduction of the identified deterioration processes, in terms of probability and potential impact. Moreover, complementary information on these risks is requested, covering the potential impact on visitors, whether they can be considered sudden events and, finally, whether they can be related to the effects of climate change.

The actual risk calculation is carried out in another sheet (7, Risk) based on the data collected in the rest of the sheets. Thus, for each of the 9 deterioration factors considered, the data are integrated into a calculation matrix, using four elements of analysis:

- Vulnerability:
  - Observed degradation (diagnosis): impact and risk observed so far;
  - Sensitivity: intrinsic characteristics of materials, techniques, site or environment;
- Hazard:
  - Evidence (or quantification) of each of the degradation factors.
  - Exposure: complementary factor that facilitates or cooperates in the agent's action;

The number of items considered for calculating the risk associated (Table 2) with each agent is variable, although we are obviously aware that this number will need to be reviewed and probably increased in the future.

The calculation of the risk (for each factor, Rx) is obtained from the product of the four variables, and is in turn related to the maximum risk (Rmax), using the following rules:

1.1) Initial risk, for each factor (iRx) = (1 × 2*3 × 4)

Table 2
Information used for the quantification of the risk by water/moisture (all values from 0 to 4 (0–1, low risk; 1–2, medium risk; 2–3, high risk; 3–4, very high risk).

Vulnerability				Hazard				Risk
Observed degradation		Sensitivity		Territorial (or measured)		Exposition		
Severity of degradation	2,7	Porosity	1,0	Climate	3,0	(Far) superficial water	4,0	
Observed risk	2,7	Level of (phisical) protection	3,0	Rain	4,0	Water drainage	1,0	**2,7**
		Wear resistance	3,0	Possibility of flooding	4,0	Solar exposition	2,7	
				Superficial water	1,0	Water impact	3,0	
						Water run-off	2,5	**High risk**

1.2) Maximum risk (Rmax) = (1 × 2*3 × 4), when all values=4
1.3) Final risk (for each factor, Rx) = (4*(iRx/Rmax))
1.4) General risk of the site = average of (nine) Rx

The calculations are always scaled to a range between 0 and 4, where 0 to 1 is low risk; 1 to 2 is medium risk; 2 to 3 is high risk and 3 to 4 is very high risk. In order to adjust the initial results (Rx, Rmax) to this scale, a linear interpolation of the results has been performed in calculations 3 and 4.

3.2. Management

The outline of management and protection strategies was intended to meet two requirements: on the one hand, the material conservation of prehistoric art in the territory covered by the LandCRAFT project; on the second hand, the design of a plan to improve social recognition of this site through the creation of a programme for the management of public visits. We consider that, in order to preserve this exceptional treasure, it is essential that both the local community and visitors appreciate and integrate it into their personal heritage.

Thus, the first task was to select the sites that could benefit from a public visit programme. This strategy used a methodology which had already been applied to other archaeological typologies [27,28], based on the register items indicated so far. It is assumed that for the presentation of a heritage site, not only the best preserved sites should be selected (diagnosis and risk), but also those with a higher heritage value. In other words, those whose cultural significance allows them to be considered relevant for the society. This value will not only justify their selection, but will also facilitate the definition of objectives and strategies for their management [29]. Basically, this means defining the criteria to be applied in order to decide which sites should be shown to the public, but also determining the extent of this exposure and even the arguments for it.

A quantification of the cultural heritage value (HV) of the sites studied was initially carried out. At this point, it should be noted that although there are many approaches to this question, we have long been using the criteria proposed by Lipe [30]: symbolic, scientific, aesthetic and economic value. Following this model, some information recorded in the sheets (Table 1) was automatically incorporated (sheet 8, heritage value). In addition, for more complex elements, a questionnaire (with a total of 30 items of a very diverse nature) was completed by the members of the research team.

This information was used to calculate two indexes: AI (actions index) and HEI (cultural heritage efficiency index), which were obtained from the following information:

- Average of complexity and urgency of protection and conservation actions (PA)
- Average of complexity and urgency of exhibition (presentation) actions (EA);
- Number of protection and conservation actions (PN);
- Number of exhibition actions (EN).

And from there:

- AI = (PA*PN) / (EA*EN)
- HEI = HV / AI

In order to separate both groups (protection vs. exhibition) a limit of 1 has been established for HEI and 2 for HV. When both indexes go beyond these values, exhibition is proposed; otherwise, mere protection (and preventive conservation) of the site is proposed.

4. Results

4.1. Risk

Table 3 and Fig. 4 show the results of the risk calculation for all the sites studied. Given the technical characteristics of the paintings and the degradation processes which affect them, the “radiation” factor has not been used in this project, as we consider its potential impact to be negligible. Only the possible thermal impact of solar radiation has been taken into account; it has been incorporated into the “climate” factor.

The data are reasonably homogeneous, slightly above 2 (average 2.2, high risk), with a maximum of 2.4 (Faia). It is obvious that the use of a large number of quantification elements tends to homogenise the results. In general, the most decisive/influential factors seem to be climatic and geo-structural, while those linked to human action are surprisingly moderate. The permanent importance of the climatic (and hydric) factor is related to the natural processes of crust formation, one of the most common in the site.

However, the maximum values at each site show the relevance of other, site-specific factors. The low values of some common risks

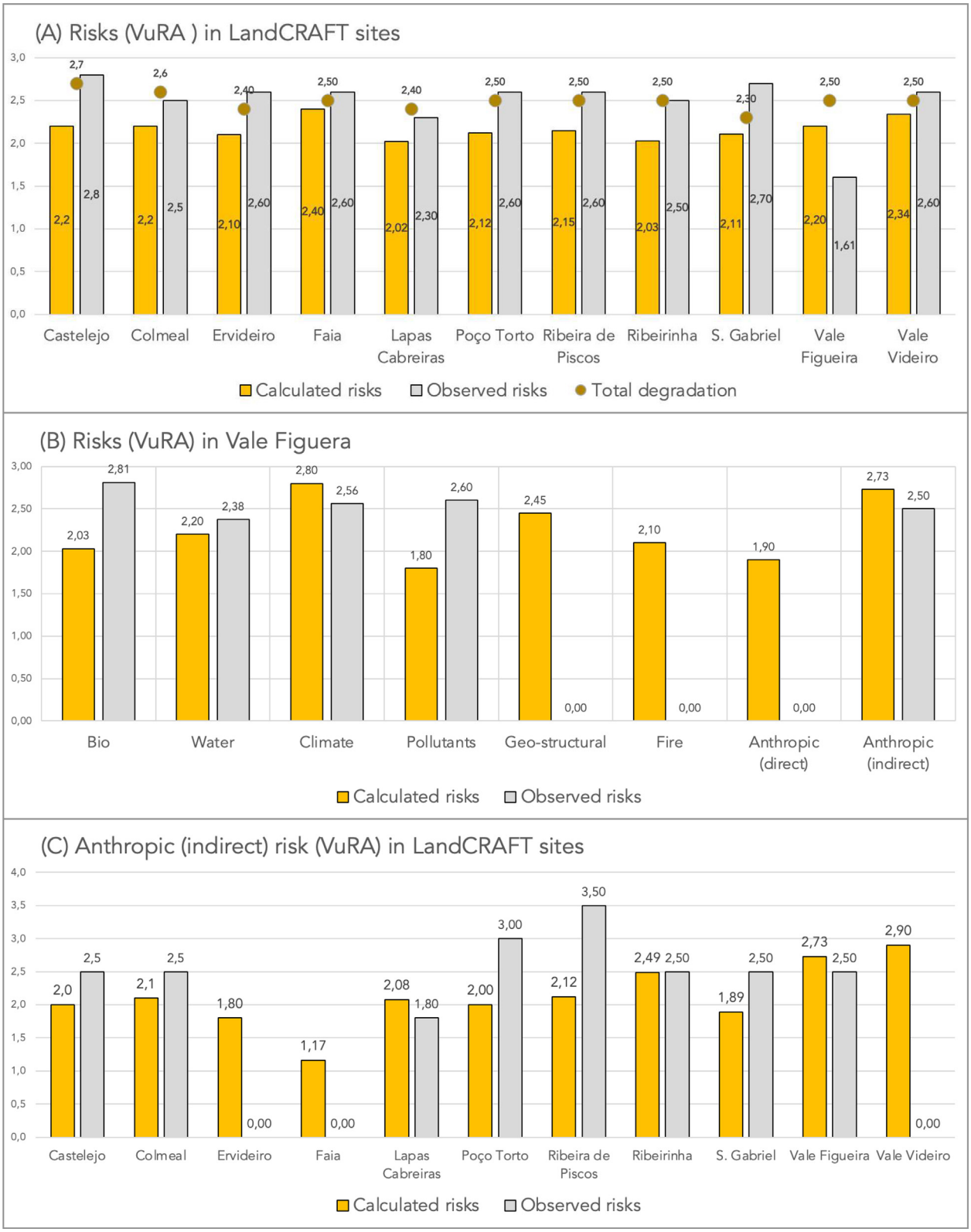

Fig. 4. Results of risk calculations: (A) observed and calculated risks, and total degradation at all LandCRAFT sites; (B) observed and calculated risks at one site (Vale Figueira); (C) observed and calculated indirect anthropic risk at all sites.

Table 3
Calculated risks (VuRA) in the sites studied in LandCRAFT project, all values from 0 to 4 (0–1, low risk; 1–2, medium risk; 2–3, high risk; 3–4, very high risk). 1. Castelejo, 2. Colmeal, 3. Ervideiro, 4. Faia, 5. Lapas Cabreiras, 6. Poço Torto, 7. Ribeira de Piscos, 8. Ribeirinha, 9. São Gabriel, 10. Vale Figueira, 11. Vale Videiro.

	1	2	3	4	5	6	7	8	9	10	11	Avg
Biology	2,0	2,4	2,2	2,3	2,0	2,0	1,9	2,1	**2,5**	2,0	1,9	**2,1**
Water	2,4	2,4	**2,8**	**2,4**	2,0	2,2	2,4	1,6	**2,5**	2,2	2,2	**2,3**
Climate	2,9	2,1	2,2	**2,4**	2,0	**2,7**	**2,8**	1,7	2,3	**2,8**	**3,0**	**2,4**
Pollutants	1,9	2,2	1,8	2,0	1,3	1,9	1,8	1,2	1,9	1,8	1,8	**1,8**
Geo-structural	2,8	1,7	2,0	2,0	2,0	**2,7**	2,3	2,1	2,2	2,5	2,8	**2,3**
Fire	1,8	2,1	1,8	2,0	2,1	2,1	1,9	2,3	1,8	2,1	2,2	**2,0**
Anthropic (direct)	1,8	**2,6**	1,8	1,8	2,0	2,0	2,0	2,0	1,9	1,9	1,9	**2,0**
Anthropic (indirect)	2,0	2,1	1,8	1,2	**2,1**	2,0	2,1	**2,5**	1,9	2,7	2,9	**2,1**
Total	**2,2**	**2,2**	**2,1**	**2,4**	**2**	**2,2**	**2,2**	**2,0**	**2,1**	**2,2**	**2,3**	**2,2**
Max	**2,9**	**2,6**	**2,8**	**2,4**	**2,1**	**2,7**	**2,8**	**2,5**	**2,5**	**2,8**	**3,0**	**2,4**
Min	**1,8**	**1,7**	**1,8**	**1,2**	**1,3**	**1,9**	**1,8**	**1,2**	**1,8**	**1,8**	**1,8**	**1,8**

Fig. 5. General view of the Vale Figueira site, on the banks of the river Côa and exposed to flood risk from construction work (indirect anthropic) downstream.

in rock art (fire, pollutants) are probably the result of the socio-ecological conditions of the environment, with not too lush vegetation, not too intensive land use, and little pollution.

For and adequate quantification of risk, it is essential to point out the difference between the "observed" and the "calculated" calculation. Fig. 4.A shows the total risk at the sites visited, with an evident (and misleading) tendency to overestimate the observed risk. The observed risk is therefore partial data that we link to vulnerability, but the relevant information is the calculated risk (vulnerability and hazard). Fig. 4.B shows the risks at one site (Vale Figueira) (Fig. 5), being remarkable the absence of observed risks in some factors (geo-structural, fire and anthropic direct) that do not show evidence of damage at present. In this case, the tendency to overestimate the observed risk is not so pronounced, with some calculated risks (climate, anthropic indirect) being higher. Fig. 4.C shows the total risk of a single agent (anthropic indirect) for all sites. Again, the absence (observed) at some sites is striking, while the calculated risk is more diverse, with very high (2.9 at Vale Videiro) but also very low risks (1.2 at Faia) at remote, not easily accesible sites.

In general, the calculated risks are consistent with the specific characteristics of each of the sites studied. Thus, in the sites closest to inhabited areas or communication routes, the anthropic risks increase (Colmeal, Ribeirinha, etc.), while in the more remote sites, climatic factors are dominant.

4.2. Management

Table 4 and Fig. 6 show the HV and HEI results for the sites studied. There is a reasonable difference in the HV of the 11 sites studied (maximum: 3.1, minimum: 1.2), which in fact derives from the multiplicity of elements considered and the specific characteristics of the site. As indicated above, in order to decide which sites should be exhibited, two requirements were established: the HV should be greater than 2, and the HEI greater than 1. As a result, it is proposed not to exhibit Castelejo, São Gabriel and Vale Videiro, so in these cases, the actions related to public presentation are not incorporated into the action proposal.

On this basis, we outlined a management strategy for each site. The system (sheet 9) automatically generates a conservation protocol and, of course, indications on future maintenance and monitoring. Should it be the case that the site is going to be presented to the public, it will be necessary to carry out a greater number of actions, including the creation of accesses, information facilities, etc. However, all sites obviously require conservation and protection work.

Moreover, in all of the sites, the results of the risk calculation require the revision and reinforcement of the actions initially proposed, or simply the design of actions not considered until then. As indicated above, some hazard factors were not identified during the diagnosis process.

Table 4
Heritage value (HV) and heritage efficiency value (HEI) in the sites studied in LandCRAFT project, all values from 0 to 4; 1. Castelejo, 2. Colmeal, 3. Ervideiro, 4. Faia, 5. Lapas Cabreiras, 6. Poço Torto, 7. Ribeira de Piscos, 8. Ribeirinha, 9. São Gabriel, 10. Vale Figueira, 11. Vale Videiro. Yellow indicates sites for which no public exhibition is proposed.

	1	2	3	4	5	6	7	8	9	10	11	Avg
Economic value	1,0	3,0	0,8	1,2	3,3	2,2	**3,4**	2,6	0,9	2,6	0,8	**2,0**
Aestethic value	1,7	2,8	2,8	2,6	**3,0**	2,6	2,6	2,3	1,5	2,3	1,7	**2,4**
Simbolic value	1,4	2,6	1,8	**3,1**	3,0	2,1	2,4	1,5	1,4	2,0	1,5	**2,1**
Scientific value	1,7	2,5	**3,2**	**3,2**	3,1	2,8	2,6	2,3	1,1	2,3	2,3	**2,5**
Total HV	**1,5**	**2,7**	**2,1**	**2,5**	**3,1**	**2,4**	**2,7**	**2,2**	**1,2**	**2,3**	**1,6**	**2,2**
HEI	**1,9**	**2,1**	**2,8**	**1,2**	**1,1**	**6,7**	**1,8**	**1,8**	**1,4**	**3,4**	**1,4**	**2,3**

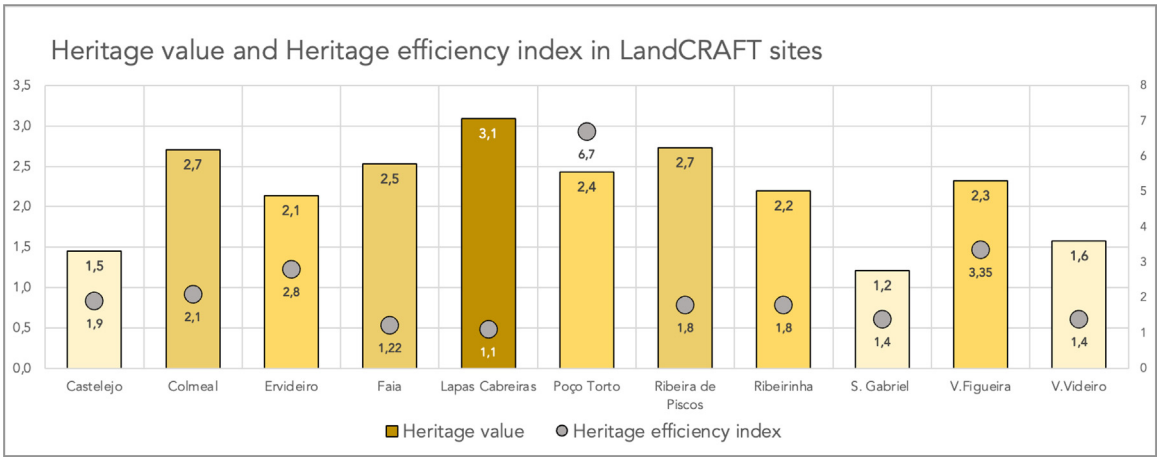

Fig. 6. Results of heritage value and heritage efficiency index calculations at all LandCRAFT sites, all values from 0 to 4.

5. Final discussion and conclusions

In the case of the LandCRAFT project, the VURA system has served to standardise, organise and manage a large amount of information about vulnerability and hazardousness, and finally risk. Consequently, it has served to outline in detail the management strategies (protection, presentation, conservation, etc.) of the set of sites covered by the project. We believe that the VuRA proposal is an interesting contribution to the management of archaeological sites with rock art. In general terms, the results are consistent and adequate for what could have been expected initially.

However, the model is not considered finalised, but a first version of a procedure that still needs to be matured and improved. For example, input is mostly manual and only some calculations are automatic. Therefore, it is advisable to incorporate more automatic (geo-referenced) data, in a real GIS app, and move towards expert systems that improve automation. Undoubtedly, this would be much easier if we had a national (GIS) hazard management tool, as in the Italian example.

Of course, the factors considered for calculating risk can and should be reviewed and completed, even by modifying the weighting of some of them. We also consider it necessary to diversify and provide more details on the proposals for action (which for the time being are still schematic), even improving the automation of the relation between actions and calculated risks.

Calculations connected to site management (HV, HEI) have provided suggestions on the typology of action, but are considered to be merely advisory: they should be regarded as an initial opinion. In fact, some sites (Ervideiro, Faia) with high value (and HEI) cannot really be exhibited given the current constraints (difficult access, etc.). The final decision depends on other actors (authorities, local population, researchers, etc.) who will be able to expand (or reduce) the ambitions of the proposal. In fact, VuRA is only considered a necessary part of a wider group of actions to be organised in a real management plan for the whole set of sites.

In any case, the development of this tool has helped us to understand that there is a need and scope for research to promote much more efficient tools, and also that these tools are of enormous interest to facilitate and improve decisions on the management of cultural heritage in general and rock art in particular. In short, any risk quantification system must consider: 1) the sensitivity of the object to deterioration, its characteristics and state of conservation; 2) the hazard, the degradation factors present, their evolution and future probability and 3) the quantification of the possible impact on the object, the risk. Based on all this, it is important to adopt some strategies to contain deterioration and risk, through a wide range of protection and conservation actions. The future challenges seem to be related to the development of the three tasks indicated above, especially the last one (quantification of risk). And for this to be achieved, an ambitious research policy must be ordered and encouraged:

- Firstly, it is necessary to create risk charts (or maps) that incorporate territorial hazardousness into heritage management. There is a large supply of geo-referenced information sources for some factors, and even calculation models that can be transferred to cultural heritage [30]. It is therefore a question of combining all this information, together with the catalogue of sites, in GIS applications that offer automatic risk (or at least hazard) calculations.
- In parallel, and especially for persistent risks, it is necessary to quantify local risk more accurately. This requires the standardisation of agent measurement processes and, more importantly, the design of mathematical models for estimating risk [31].
- It is imperative to design, even on an international scale, vulnerability reports that can be produced for all the rock art sites.

Or, in other words, it seems necessary to standardise cataloguing proposals that incorporate vulnerability;
- It is essential to integrate all of the above (hazardousness and vulnerability) into models that provide automatic risk calculations, adapted to each site;
- Furthermore, in the medium term we might expect to see the design of expert systems that simplify local inspection to provide, from geo-referenced locations alone, individual risk estimates [32].

All this, of course, should be very useful to propose protection and conservation actions adapted to the vulnerability of each site, which can also be automated. And even, again, advanced through expert systems [33].

We suggest that all those researchers interested join us in this essential task.

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